# FELDSPAR UPGRADING FOR MAGDALEN SILICA INC.

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MICROMEDIA

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# FELDSPAR UPGRADING FOR MAGDALEN SILICA INC.

by

G.I. Mathieu*

## ABSTRACT

Marine sands are principally composed of quartz, aluminosilicates, ferromagnesian minerals with minor amounts of heavy metal oxides including ilmenite, hematite, rutile and, in particular, limonite. The latter occurs as a strongly adhering coating on both the quartz and feldspar grains. A 100 million tonne deposit of this nature has been identified offshore from the Magdalen Islands in the Gulf of St. Lawrence. Such reserves, if processed economically, can provide the Eastern provinces with silica and feldspar products for nearly half a century.

The Canadian Centre for Mineral and Energy Technology (CANMET) has thus undertaken research to find the most economical and environmentally acceptable processes for beneficiating this raw marine sand, which contained 88% quartz and 10% feldspar, as the main values. Foundry sand and silica concentrate of glassmaking quality were first produced in the CANMET pilot plant (1981-82). The current study was specifically aimed at upgrading the feldspathic sand byproduct to commercial value.

The procedure developed included a selective flotation stage for the removal of the remaining free quartz, with the floated feldspar being subsequently cleaned by acid leaching and/or magnetic separation to meet the iron oxide specifications of various glass and ceramic materials. Flotation parameters, leaching conditions and types of magnetic separation used for optimum results are described in detail.

Three integrated flowsheets were tested with all the products analysed and metallurgical balances computed. The features of these are a progressive processing approach to minimize the operating costs and equipment requirements.

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# L'AMÉLIORATION DU FELDSPATH POUR LA MAGDALEN SILICA INC.

par

G.I. Mathieu*

## RÉSUMÉ

Les composants principaux des sables marins sont les aluminosilicates et les minéraux ferromagnésiens avec des petites quantités d'oxydes de métaux lourds comme l'ilménite, l'hématite, le rutile et surtout la limonite. Cette dernière existe sous forme d'une couche solidement adhérée aux grains de quartz et feldspath. Un tel gisement d'un million de tonnes a été découvert près des côtes des Iles-de-la-Madeleine dans le golfe du St. Laurent. De telles réserves, si l'on les exploite de façon économe, pourraient fournir aux provinces de l'est des produits en silice et en feldspath pour une période d'environ cinquante ans.

Le Centre canadien de la technologie des minéraux et de l'énergie (CANMET) a donc entrepris de la recherche afin de découvrir les méthodes les plus efficaces, du point de vue de l'économie et celui de l'environnement, pour enrichir ce sable marin brut, dont les principales valeurs sont le quartz et le feldspath à des teneurs de 88% et 10%, respectivement. Dusable de fonderie et un concentré de silice d'une qualité qui satisfait à la fabrication de verre furent produits au cours des années 1981-82 à l'installation pilote du CANMET. La présente étude vise surtout à améliorer la qualité du sous-produit du sable feldspathique en vue de le rendre commercialement acceptable.

La procédure mise en valeur comprend une phase de flottation sélective pour l'enlèvement du quartz libre restant, suivi d'une lixiviation acide et/ou d'un triage magnétique pour satisfaire aux exigences en oxyde de fer de divers matériaux céramiques et de verrerie. On décrit de façon détaillée les paramètres de flottation, les conditions de lixiviation et les type de separateurs magnétiques que l'on a employés pour obtenir les meilleurs résultats.

On a mis à l'essai trois schémas de traitement, analysé tous les produits et calculé les balances métallurgiques. Ces shémas mettent l'accent sur une méthode progressive de traitement qui peut réduire au minimum les dépenses d'exploitation et les besoins en équipement.

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## NOMENCLATURE AND ABBREVIATIONS

**Flotation:**

minute = min
kilogram/tonne (dry feed) = kg/t
propane diamine dioleate = PDD
scrub and float = SF
acid alkali treatment and float = AAF
sized split flotation = SSF
coarse flotation = C
fine flotation = F

**Acid Leach:**

volume = v
hour = h
degree centigrade = °C
solid/liquid by weight = s/l

**Magnetic Separation:**

high intensity = H-I
high gradient = HGMS
magnetic field intensity unit =
Tesla = 10,000 gauss

## SUMMARY OF PROCESSES AND RESULTS

For upgrading feldspar to market specifications, three main approaches were successful. These consisted basically of differential feldspar flotation after either alkali scrubbing or acid-alkali treatment, followed by sulphuric acid leach and/or magnetic separation for removing iron stains and minerals. After the alkali attrition, both sized and unsized flotation was tested with favourable results. Under adequate processing conditions, the final concentrates satisfied the alumina, alkali and iron requirements of various feldspar commercial products, as shown below:

Table 1 - Analysis of processed feldspar products

| FELDSPAR SPECIFICATIONS | | PROCESSES and RESULTS | | |
|---|---|---|---|---|
| | | Alkali Scrubbing and Flotation | | Acid-Alkali Treatment and Flotation |
| | | Unsized | Sized | |
| Alumina (% $Al_2O_3$) : 18.0 (min)<br>Alkalis (% $K_2O$ + $Na_2O$): 13.0 (min) | | 18.0-18.2<br>13.6-14.0 | 18.0-18.3<br>13.5-14.1 | 18.3-18.4<br>13.9-14.0 |
| IRON OXIDE (% $Fe_2O_3$) | Coloured glass: 0.25-0.30 | (Plus HI - dry magnetic separation)<br>0.27 | 0.27 | - |
| | Flint glass: 0.1 (max) | (Plus acid leach)<br>0.12 | 0.11 | 0.11 |
| | Ceramic grade: 0.08 (max) | (Plus grinding and HGMS wet magnetic separation)<br>0.08 | 0.076 | 0.079 |
| | Porcelain: 0.05 (max) | (Plus acid leach at minus 45 µm)<br>0.050 | 0.049 | 0.051 |

The above tabulation illustrates the progressive processing pattern used in this study with the magnetic separation and acid leach being used only on a fraction of the production, when required to satisfy iron requirements. The overall feldspar recovery in the above products varied from 86.5 to 90.2% depending on the flowsheet used.

# INTRODUCTION

## DEFINITION, PROPERTIES AND USES OF FELDSPARS

In mineralogical terms feldspars are aluminosilicates of potassium (orthoclase), sodium (albite) and, to a lesser extent, calcium (anorthite), with the following compositions:

| Mineral | Formula | % $K_2O$ | % $Na_2O$ | % CaO | % $Al_2O_3$ | % $SiO_2$ |
|---|---|---|---|---|---|---|
| Potash feldspar | $K\,AlSi_3O_8$ | 16.9 | - | - | 18.3 | 64.7 |
| Soda feldspar | $Na\,AlSi_3O_8$ | - | 11.8 | - | 19.4 | 68.7 |
| Lime feldspar | $Ca\,Al_2Si_2O_8$ | - | - | 20.1 | 36.6 | 43.3 |

The alkali feldspars provide valuable fluxing properties both for glass and ceramic manufacturing. Despite their wide-ranging occurrence in the earth's crust, only a small number of the known feldspar deposits are suitable as fluxes because most are either too fine-grained or highly contaminated by iron minerals. Consequently, until now only a few pegmatite dykes have been processed commercially.

Although they have been largely replaced by nepheline-syenite in the Canadian glass industry, alkali feldspars still retain a major share of the ceramic, pottery, china and white ware manufacturing. They are preferred in most ceramic applications, because of the less violent action and better temperature control for the different degrees of vitrification required. Furthermore, the low conductivity of the high potash feldspar makes it particularly suitable for electrical porcelain. Notwithstanding the present slackness in the economy, demand for these purposes remains high and prices attractive. According to a recent survey by Boyd (1), "the increasing requirements in electrical energy could elevate potash feldspar (essential in high voltage porcelain) to a position of prime economic importance". In addition to fluxing agents, the feldspathic minerals are also used in the manufacture of glass for the disposal of radioactive waste materials, as a component of fertilizers an abrasive in scouring powder, a constituent in roofing tiles, as well as in paints, enamels, rubbers and plastics, both as filler and extender (2).

Canada has been importing over the recent years most of its feldspar at rapidly increasing prices, as evidenced by the following statistics:

Table 2 - Canadian Imports of Crude and Ground Feldspar*

| Year | Tonnes | $ | $/t |
|---|---|---|---|
| 1976 | 4 053 | 106 000 | 26.15 |
| 1977 | 4 271 | 275 000 | 63.38 |
| 1978 | 4 586 | 762 000 | 166.16 |
| 1979 | 4 589 | 501 000 | 109.10 |

*Sources: Statistics Canada; Energy, Mines and Resources.

With further growth and diversification of the above mentioned markets in the coming years, the development of a Canadian feldspar producer should certainly have a high priority for governmental support and assistance. Because of its possibilities on international markets, the production of a high-potash feldspar would be particularly interesting in this regard.

## CONVENTIONAL FELDSPAR PROCESSING

The common technology to produce feldspar from pegmatites in North America was summarized by Redeker (3), as follows: "The granular material, containing mainly quartz and potash feldspar, is dewatered, blended and stockpiled for mica flotation and feldspar-quartz separation. The stockpiled material is metered to a high-intensity attrition scrubber after which it is deslimed in a cyclone and conditioned with sulphuric acid and petroleum sulphonate for mica and iron flotation. After further desliming and conditioning with hydrofluoric acid and tallow amine acetate, the quartz-feldspar separation flotation is achieved. The high potash feldspar is filtered on a belt filter and dried. The quartz is dewatered and stockpiled wet. Feldspar is sold as is, after drying and magnetic separation for specialty glass, or ground to specifications in a ceramic-lined mill as pottery feldspar. The quartz is dried, sized and sold as container glass sand".

Although the feldspar flotation process was well established in the U.S.A. by the late 1950's, it was only in 1966 that Europe's first plant was built by Oy Lohja AB in Finland. In this case, after floating and screening the mica the slurry is transferred to the feldspar flotation circuit in which hydrofluoric acid and an amine are used as floating agents. The fluids are recirculated as much as possible to conserve the acid, while the waste is neutralized with calcium oxide before discharge. The 28 mesh feldspar product undergoes magnetic separation to remove any iron content and a portion is ground to minus 75 and 50 µm to suit the ceramic industries. At Glamsland in southern Norway, a three stage flotation process is used in which the iron-bearing minerals are removed first, the feldspar and quartz are subsequently separated and, finally, the feldspar is split into soda and potash fractions; this final separation makes the process unique. The quartz and soda feldspar undergo further flotation before dewatering and magnetic separation (4).

Currently, the general tendency is to eliminate the HF and tallow amine acetate in favour of sulphuric acid, a better pH control and a dioleate as the feldspar collector. The advent of more effective high-intensity magnetic separators has also rendered the iron flotation unnecessary in some cases. Our work was directed toward the application of this new technology (5,6).

## PREVIOUS WORK ON MAGDALEN QUARTZ-FELDSPAR SAND

Pilot-plant studies were made in 1981 at the Canada Centre for Mineral and Energy Technology (CANMET) on a sample of the raw Magdalen sand. The material was said to be representative of a 100 Mt deposit, which was claimed by Magdalen Silica Sand, Inc. in the Gulf of St. Lawrence, near the Magdalen Islands. This marine sand contained 88% quartz and 10% feldspar, with the remaining 2% being composed mainly of sea shells, heavy minerals and limonite coating on the silica and silicate grains. The primary flotation separation of the minerals gave the results illustrated in Fig. 1.

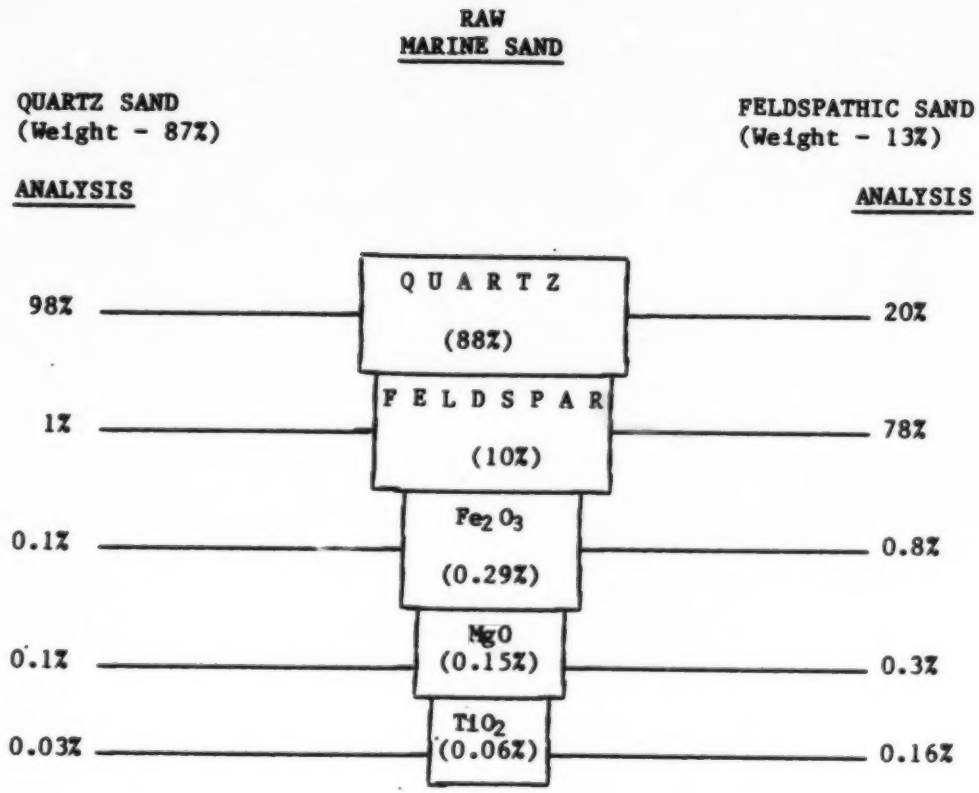


Fig. 1 - Separation of Minerals in Primary Feldspar Flotation

The silica sand at 98.1 to 98.4% quartz, with an AFS Number of 49 and an angularity coefficient of 1.1, was readily acceptable for steel foundry and tested with satisfaction in this application. It was also suitable for the manufacture of coloured glass. The iron oxide level, on the other hand, was slightly too high for clear glass. Iron was then reduced to 0.03% $Fe_2O_3$ by a sulphuric acid-leach stage. This study was reported in detail in our Report MRP/MSL 82-5 (CR) (7).

## PURPOSE OF INVESTIGATION

The specific objective of the current work was to upgrade, at minimum cost, the feldspathic sand from 14.3% $Al_2O_3$, 8.4% $K_2O$, 1.9% $Na_2O$ and 0.61% $Fe_2O_3$, to finished feldspar products of both glass and ceramic grades, as specified in Table 3.

Table 3 - Requirements of commercial feldspars

| Chemical composition | Category of Feldspar Glass-grade | Ceramic-grade |
|---|---|---|
| Alumina ($Al_2O_3$) | 18.5±0.6% | 18.0% (min) |
| Alkalis ($K_2O$+$Na_2O$) | 12.5± 1.0% | 13.0% (min) |
| Iron oxide ($Fe_2O_3$) | 0.1% (max) | 0.08 (max)* |
| Size range: | 95% within 420 and 74 µm | 100%-74 µm (95%-45 µm for porcelain) |

*0.05% $Fe_2O_3$ is prefered for electrical porcelain.

## ANALYTICAL METHODS

In this work, the determinations of low alumina, iron, magnesium and titanium oxides were all made by optical emission spectrometry. The higher alumina, iron, magnesium and titanium, as well as all the $K_2O$, CaO and total $SiO_2$ were determined by X-ray analysis. Finally, sodium oxide and quartz were chemically analysed. Wet chemistry was also used periodically to verify the instrumental determinations, which proved to be very reliable.

The total feldspar content was calculated according to the stoichiometrical formula:

$$\text{TOTAL FELDSPAR (\%)} = \left(\frac{K_2O}{16.92} + \frac{Na_2O}{11.82} + \frac{CaO}{20.16}\right) 100$$

Occasionally, the total feldspar was calculated by multiplying the % $Al_2O_3$ by the factor 4.9 and the quartz obtained by difference, i.e., % quartz = 100 -(% feldspar + % metal oxides + % LOI).

## FELDSPAR UPGRADING STUDY

### CHEMICAL ANALYSIS, SIZE DISTRIBUTION AND MINERALOGICAL COMPOSITION OF FELDSPATHIC SAND

A 1-kg sample was riffled out from the 40-kg lot of the primary feldspar concentrate produced previously, from which a portion was pulverized and fully analysed with the following results:

Table 4 - Chemical analysis of head sample

| Feldspar Constituents, % | | | | Silica % | | Metal Oxides % | | | Loss on Ignition % |
|---|---|---|---|---|---|---|---|---|---|
| $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | Total | Quartz | $Fe_2O_3$ | MgO | $TiO_2$ | LOI |
| 14.3 | 8.4 | 1.9 | 0.46 | 72.9 | 33.4 | 0.61 | 0.26 | 0.11 | 0.9 |

A 300-g cut from the head sample was screened on U.S. standard series sieves. The sized fractions were weighed and assayed for the feldspar components, total silica and major metal oxides, with the results reported in Table 5. The total feldspar content in each sized fraction was also calculated and plotted as a function of size in Fig. 2.

Table 5 - Size analysis of feldspathic sand

Part 1 - Weight and Analysis

| Size | | Weight | Analysis, % | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| µm | US No. | % | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | $SiO_2$ | $Fe_2O_3$ | MgO | $TiO_2$ | Feldspar |
| -600+300 | 30 x 50 | 20.1 | 17.6 | 10.1 | 2.3 | 0.80 | 67.2 | 0.60 | 0.24 | 0.07 | 83.1 |
| -300+250 | 50 x 60 | 33.8 | 16.2 | 9.8 | 2.1 | 0.46 | 69.1 | 0.50 | 0.22 | 0.06 | 78.0 |
| -250+210 | 80 x 70 | 16.4 | 15.5 | 9.5 | 1.8 | 0.37 | 74.6 | 0.56 | 0.25 | 0.06 | 73.2 |
| -210+180 | 70 x 80 | 16.3 | 12.8 | 7.1 | 1.7 | 0.34 | 76.0 | 0.60 | 0.29 | 0.09 | 58.0 |
| -180 | minus 80 | 13.4 | 8.4 | 4.2 | 1.2 | 0.35 | 83.2 | 0.93 | 0.40 | 0.23 | 36.7 |
| Feed (calcd) | | 100.0 | 14.8 | 8.6 | 1.9 | 0.48 | 72.6 | 0.60 | 0.26 | 0.09 | 69.3 |

Part II - Material Balances

| Size | | Distribution, % | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| µm | US No. | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | $SiO_2$ | $Fe_2O_3$ | MgO | $TiO_2$ | Feldspar |
| -600+300 | 30 x 50 | 23.9 | 23.6 | 24.4 | 33.6 | 18.5 | 20.0 | 18.2 | 15.7 | 24.0 |
| -300+250 | 50 x 60 | 37.1 | 38.4 | 37.6 | 32.4 | 32.2 | 27.9 | 28.1 | 22.7 | 38.0 |
| -250+210 | 60 x 70 | 17.3 | 18.1 | 14.8 | 12.7 | 16.8 | 15.2 | 15.5 | 10.9 | 17.3 |
| -210+180 | 70 x 80 | 14.1 | 13.4 | 14.7 | 11.5 | 17.1 | 16.2 | 17.9 | 16.4 | 13.6 |
| -180 | minus 80 | 7.6 | 6.5 | 8.5 | 9.8 | 15.4 | 20.7 | 20.3 | 34.3 | 7.1 |
| Total (calcd) | | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

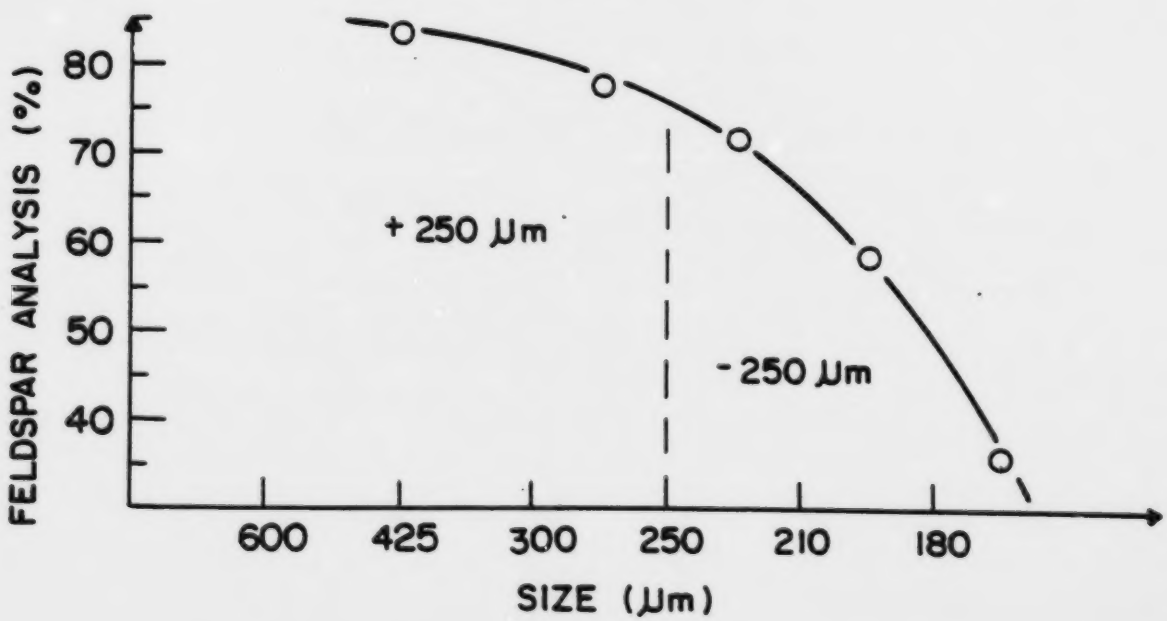


Fig. 2 - Feldspar Grade as a Function of Size

Examination of this curve suggests a separate treatment of the coarser material (e.g., the fraction larger than 250 μm), since it already contains 16.7% $Al_2O_3$, 9.9% $K_2O$ and 2.2% $Na_2O$ and would thus need very little beneficiation to satisfy the alumina and alkali requirements of the glass and ceramic feldspars. On the other hand, the finer material at 12.5% $Al_2O_3$, 7.1% $K_2O$ and 1.7% $Na_2O$ would require more extensive processing to obtain the desired grade.

The mineralogy of the primary feldspar concentrate was reported by Petruk and Mainwaring (8,9). A summary follows.

Table 6 - Mineralogical composition of primary feldspar product

| MINERALS | | | APPROXIMATE % |
|---|---|---|---|
| CATEGORY | NAME | FORMULA | |
| Silica | Quartz | $SiO_2$ | 25-30 |
| Feldspars | Orthoclase | $KAlSi_3O_8$ | 50-55 |
| | Albite* | $NaAlSi_3O_8$ | 14-16 |
| | Anorthite* | $CaAl_2Si_2O_8$ | 1- 2 |
| Metal oxides | Ilmenite | $FeTiO_2$ | 0.2-0.3 |
| | Hematite | $Fe_2O_3$ | 0.1-0.2 |
| | Limonite | $HFeO_2nH_2O$ | 0.1-0.2 |
| | Rutile | $TiO_2$ | 0.05-0.1 |
| Ferro-magnesians** | Chlorite | $A_6(AlSi_3O_{10})(OH)_8$ | 0.1-0.3 |
| | Biotite | $A\ B_3(Al,Si)_4O_{10}(OH,F)_2$ | 0.05-0.1 |
| | Pyroxene | $A\ B\ (Si_2O_6)$ | 0.01-0.05 |
| | Amphibole | $A_2B_5(Si,Al)_8O_{22}(OH)_2$ | Trace |
| Clay (Fe-rich type) | | Fe, Al, Si... | 0.1-0.2 |
| Spinel (Cr-Fe-Al type) | | $(Mg, Fe, Cr)\ Al_2O_4$ | Trace |
| Zircon | | $ZrSiO_4$ | Trace |
| Apatite | | $A_5(RO_4)_3(F,OH,Cl)_3$ | Trace |

* Often occurring in solid solution termed plagioclase.

**In the formulas of ferromagnesians, A = K for biotite, Na, Ca for amphibole, Na, Ca, Mg, Fe for pyroxene and Mg, Fe, Al, Mn for chlorite, and B = Mg, Fe and Al.

Some significant mineralogical observations follow:

1) The potassium (K) and plagioclase (Na, Ca) feldspars are largely liberated from quartz, but often contaminated by inclusions of iron- and titanium-bearing minerals.
2) Discrete grains of ilmenite, hematite, rutile, chlorite and biotite, which accounted for about half of these minerals, were also observed. With the exception of rutile, these minerals are paramagnetic.
3) Limonite and the iron-rich clay mineral are present as stains on the quartz and, to a greater extent, on the feldspar grains.
4) Pyroxene, amphibole and zircon are extremely rare; only one grain of apatite and spinel were observed in the many fields examined.

Some of these features are illustrated in Fig. 3 and 4.

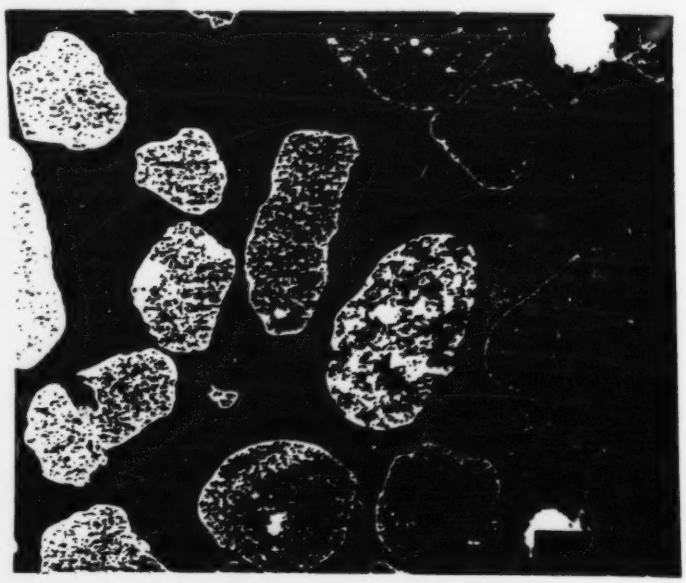

Fig. 3 - The dark grey grains are quartz, the light grey ones are fledspar and the white particles are ilmenite, rutile and spinel.

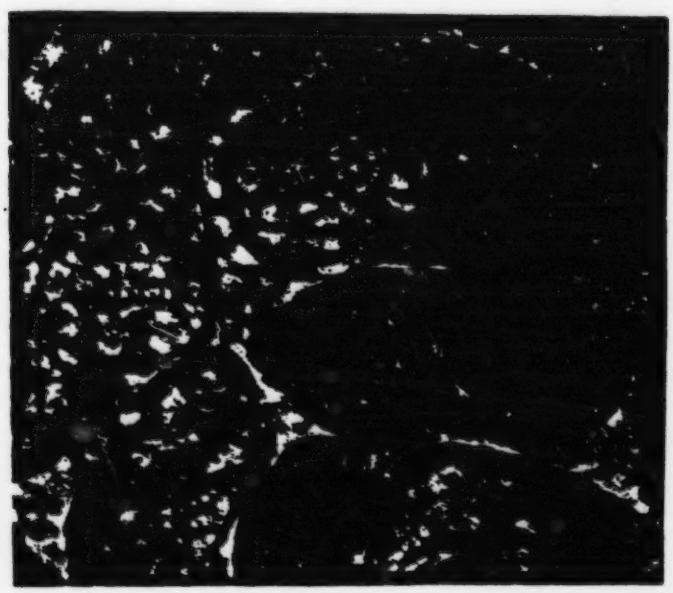

Fig. 4 - Turpid quartz and alkali-feldspar(F) grains with opaque inclusions of Fe-Ti bearing minerals; Transmitted light, 1-mm view.

Fig. 3 and 4 - Photomicrographs of Magdalen Quartz and Feldspar Sand

The mineralogy indicated the necessity of three main unit operations to fully beneficiate the feldspar, namely, (i) flotation to separate the feldspar from the free quartz, (ii) acid leach to dissolve the iron oxide coating on the valuable minerals, and (iii) magnetic separation to remove the acid-insoluble iron minerals from the feldspar products. For the ceramic grade, grinding shall be necessary prior to the magnetic separation stage for greater iron removal.

## SEPARATION OF FELDSPAR FROM QUARTZ BY FLOTATION

To be of high commercial value, a feldspar product must contain at least 18% $Al_2O_3$. Since mineralogical examination of the primary feldspar product indicated a high proportion of free quartz, the first upgrading procedure tested was thus selective flotation. No significant mineral separation however, was obtainable without treatment of the grain surfaces (highly coated with chemicals). To this aim, grinding, scrubbing and acid leaching were investigated successively. In the case of the pre-treatment by acid leach, a subsequent alkali attrition was necessary to restore feldspar floatability. After each treatment, differential flotation was tested at three levels of collectors, i.e., at low concentration to achieve the best final feldspar grade, at higher dosage to maximize the recovery and, finally, at an intermediate level in attempt to optimize both grade and recovery. As in the previous primary flotation, the non-HF method was used. Since iron co-flotation was no longer desirable, only the feldspar collector, namely propane diamine dioleate, was used. Conditions and results are reported in detail in Appendix I and summarized in Table 7. Comparative grade-recovery curves are plotted in Fig. 5.

Table 7 - Conditions and results of feldspar separation flotation

| Procedure (Test) | Reagents Consumed Kg/t | | | Analysis of Feldspar Concentrates, % | | | Feldspar Recovered in Process % |
|---|---|---|---|---|---|---|---|
| | NaOH | $H_2SO_4$ | PDD | $Al_2O_3$ | $K_2O$ | $Na_2O$ | |
| Grind and float (GF-1,2,3) | - | 5.0 | 3.7 | 18.1 | 10.7 | 2.5 | 87.3 |
| | | 5.0 | 4.5 | 17.6 | 10.5 | 2.5 | 93.7 |
| | | 5.2 | 4.0 | 17.9 | 10.6 | 2.5 | 91.2 |
| Scrub, deslime and float (SF-1,2,3) | 5.0 | 3.6 | 1.1 | 18.1 | 10.8 | 2.6 | 90.3 |
| | 5.0 | 3.8 | 1.3 | 17.3 | 10.5 | 2.5 | 94.0 |
| | 5.0 | 3.8 | 1.2 | 18.0 | 10.8 | 2.5 | 92.4 |
| Acid leach, alkali scrub, deslime and float (AAF-1,2,3) | 5.0 | 100*+2.8 | 0.55 | 18.4 | 11.2 | 2.6 | 90.6 |
| | 5.0 | 100*+3.0 | 0.65 | 17.8 | 10.9 | 2.5 | 95.8 |
| | 5.0 | 100*+2.9 | 0.60 | 18.2 | 11.0 | 2.6 | 94.1 |

*Estimated $H_2SO_4$ consumed in leaching for 6% moisture lost in the cakes and ten reuses of acid.

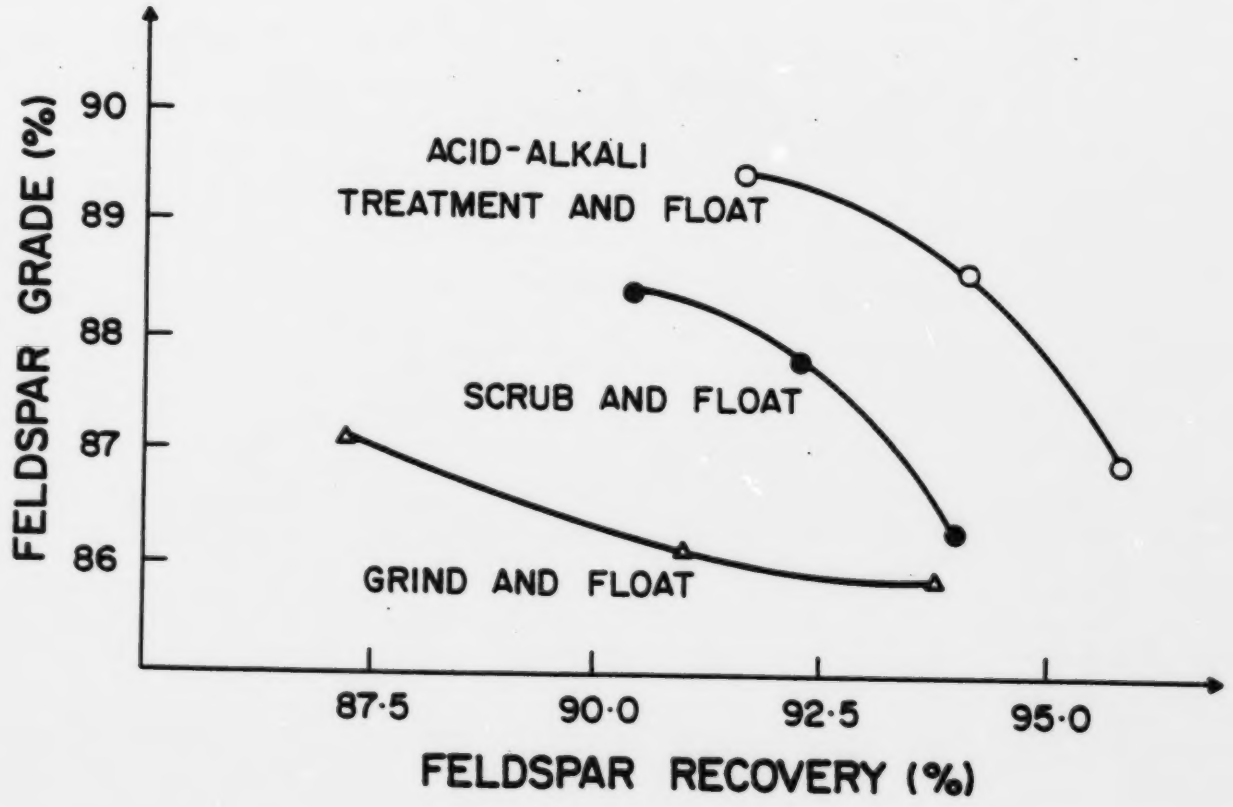


Fig. 5 - Feldspar Grade-Recovery Flotation Curves After Various Pre-treatments

The acid-alkali surface cleaning resulted in the best flotation results with an upward curve (better grade) towards the extreme right (better recovery). The procedure, when using a 6-h 70°C 35% $H_2SO_4$ leach, reduced the iron oxide level from 0.6 to 0.2% $Fe_2O_3$. To determine the size-distribution of the valuable minerals and impurities, representative samples of the floated feldspar were screened with the results shown in Table 8.

Table 8 - Sizing and analysis of flotation concentrates

| Feldspar conc (SF-1,2,3) | | | Elements analysed (%) | Feldspar conc (AAF-1,2,3) | | |
|---|---|---|---|---|---|---|
| Size (µm) | | | | Size (µm) | | |
| +300 | -300 +250 | -250 | | +300 | -300 +250 | -250 |
| 18.4 | 18.3 | 16.8 | $Al_2O_3$ | 18.6 | 18.3 | 17.8 |
| 11.2 | 11.0 | 10.1 | $K_2O$ | 11.3 | 11.2 | 11.0 |
| 2.5 | 2.5 | 2.4 | $Na_2O$ | 2.6 | 2.7 | 2.5 |
| 0.7 | 0.6 | 0.5 | CaO | 0.3 | 0.3 | 0.4 |
| 90.9 | 89.1 | 83.0 | Feldspar | 90.4 | 90.3 | 88.8 |
| 8.1 | 9.8 | 15.1 | Quartz | 9.0 | 9.1 | 10.4 |
| 0.50 | 0.42 | 0.75 | $Fe_2O_3$ | 0.15 | 0.17 | 0.24 |
| 0.14 | 0.19 | 0.35 | MgO | 0.04 | 0.04 | 0.07 |
| 0.07 | 0.06 | 0.18 | $TiO_2$ | 0.05 | 0.06 | 0.09 |

Higher grade feldspar concentrates were obtained in the coarser fractions, while the impurities reported in greater concentration in the fines (-250 µm). The trend is more pronounced with the "scrub and float" technique. This has led to try sized split flotation, as a possible means of improving the results. The dividing size selected for the separatefloats was ± 250 µm. As in previous tests, three levels of collector were investigated with each sized fraction. The processing details and the material balances are fully reported in Appendix II. The features are summarized in Table 9 and pertinent feldspar grade-recovery curves are plotted in Fig. 6.

Table 9 - Split flotation conditions and results

| Procedure | Product Size (Test) | Reagents Consumed kg/t | | | Feldspar Concentrates Analysis, % | | | Feldspar Recovery % |
|---|---|---|---|---|---|---|---|---|
| | | NaOH | $H_2SO_4$ | PDD | $Al_2O_3$ | $K_2O$ | $Na_2O$ | |
| Alkali scrub, Deslime (2X), Screen at 250 µm and Sized flotation | +250 µm (C-1) | 5.0 | 1.35 | 0.45 | 18.7 | 11.5 | 2.5 | 93.1 |
| | -250 µm (F-1) | | 1.85 | 0.95 | 17.6 | 10.4 | 2.6 | 92.8 |
| | Total (calcd) | | 3.2 | 1.4 | 18.3 | 11.1 | 2.5 | 93.0 |
| | +250 µm (C-2) | 5.0 | 1.45 | 0.55 | 18.2 | 11.3 | 2.4 | 93.6 |
| | -250 µm (F-2) | | 1.95 | 1.05 | 17.1 | 10.1 | 2.4 | 94.9 |
| | Total (calcd) | | 3.4 | 1.6 | 17.8 | 10.8 | 2.4 | 94.2 |
| | +250 µm (C-3) | 5.0 | 1.40 | 0.50 | 18.6 | 11.4 | 2.4 | 93.2 |
| | -250 µm (F-3) | | 1.90 | 1.00 | 17.4 | 10.2 | 2.5 | 93.6 |
| | Total (calcd) | | 3.3 | 1.5 | 18.1 | 10.9 | 2.4 | 93.3 |

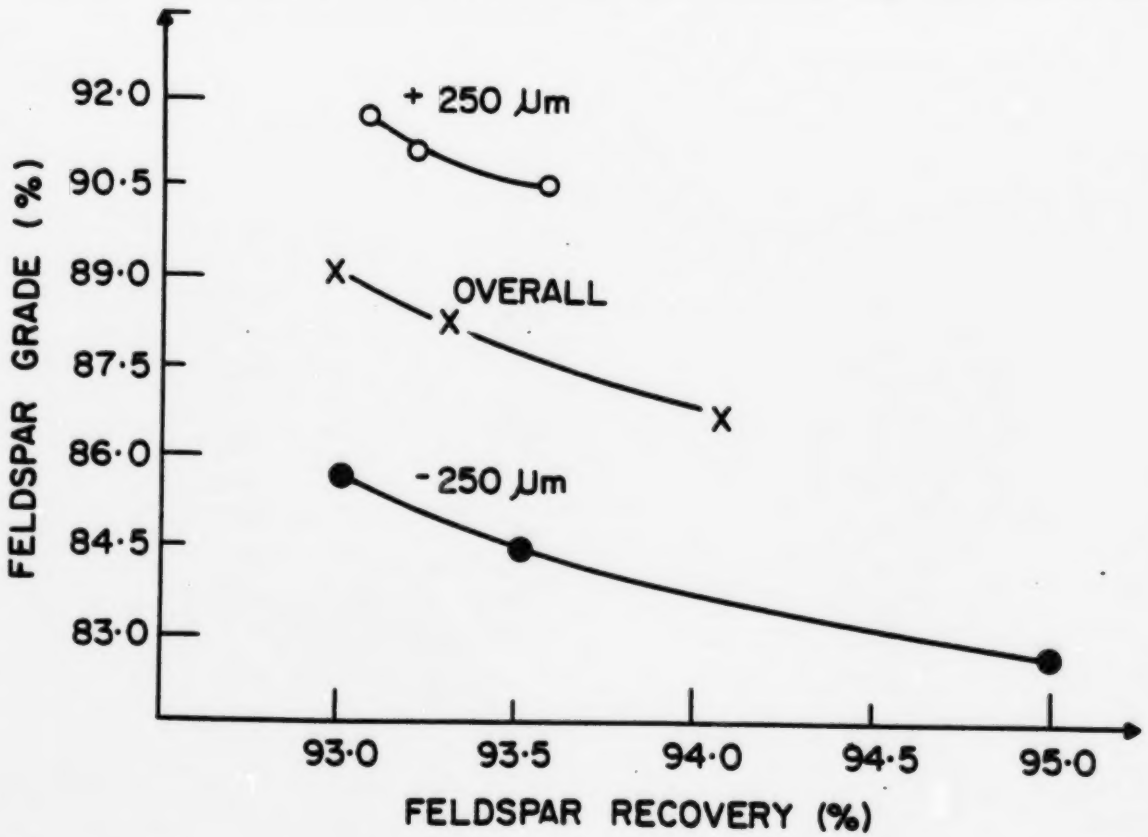


Fig. 6 - Feldspar Grade-Recovery Curves from Sized Split Flotation

Albeit somewhat more complex, the split flotation procedure improved the overall results when compared to those from the unsized scrub and float approach. However, even under the best conditions it was slightly less effective than flotation after acid-alkali treatment. These observations are evidenced by the following comparative flotation results.

Table 10 - Flotation comparative results

| Comparison Basis | Test Series | Analysis of Feldspar Concentrates, % | | | Feldspar Recovered in Process % |
|---|---|---|---|---|---|
| | | $Al_2O_3$ | $K_2O+Na_2O$ | Feldspar | |
| Maximum-grade tests | SF | 18.1 | 13.4 | 88.4 | 90.3 |
| | C+F | 18.3 | 13.6 | 89.0 | 93.0 |
| | AAF | 18.4 | 13.8 | 89.9 | 90.6 |
| Maximum-recovery tests | SF | 17.3 | 13.0 | 86.3 | 94.0 |
| | C+F | 17.8 | 13.2 | 87.4 | 94.2 |
| | AAF | 17.8 | 13.4 | 87.2 | 95.8 |
| Optimum grade-recovery tests | SF | 18.0 | 13.3 | 87.9 | 92.4 |
| | C+F | 18.1 | 13.3 | 88.2 | 93.3 |
| | AAF | 18.2 | 13.6 | 89.0 | 94.1 |

Further to the flotation testwork, it was concluded that the grind and float approach had to be discarded due to inferior results and high collector consumption, while the other three avenues were satisfactory enough to be pursued with the objective of reducing the iron oxide to glass and ceramic feldspar specifications, i.e. 0.1% and 0.08% $Fe_2O_3$, respectively.

## REMOVAL OF IRON STAINS AND MINERALS

Neither magnetic separation nor acid leach alone were capable of reducing the iron oxide to satisfactory level, but a combination of the two processes was successful. This was demonstrated by a sequence of tests involving acid leach with and without prior magnetic separation. The conditions and results of this study, which was carried out in cooperation with the Hydrometallurgy Section under the supervision of B.H. Lucas, are given in Table 11. The iron oxide analyses of the leach residues are also plotted as function of the agitation time in Fig. 7.

Table 11 - Conditions and results of magnetic separation and acid leach

| FEED | Unground Feldspar ($0.6\%\ Fe_2O_3$) | | Ground Feldspar ($0.7\%\ Fe_2O_3$) | |
|---|---|---|---|---|
| I-DIRECT MAGNETIC SEPARATION | | | | |
| Products | Stearns:0.5 Tesla, 1 mm gap | | Sala:0.9 Tesla, 20 mm/s | |
| Non-mags | $0.28\%\ Fe_2O_3$ | | $0.13\%\ Fe_2O_3$ | |
| Magnetics | $7.0\%\ Fe_2O_3$ (Feldspar lost = 4.6%) | | $4.6\%\ Fe_2O_3$ (Feldspar lost = 9.7%) | |
| II-DIRECT ACID LEACH (% $Fe_2O_3$ in Residues) | | | | |
| Time hours | $H_2SO_4$ (35% v, 70°C, 1:1) | HCl (75% v, 70°C, 1:1) | $H_2SO_4$ (35% v, 70°C, 1:1) | HCl (75% v, 70°C, 1:1) |
| 1 | 0.30 | 0.18 | 0.27 | 0.22 |
| 2 | 0.27 | 0.16 | 0.24 | 0.18 |
| 4 | 0.22 | 0.16 | 0.21 | 0.16 |
| 6 | 0.21 | 0.16 | 0.19 | 0.15 |
| III-ACID LEACH OF NON-MAGNETIC FRACTIONS (% $Fe_2O_3$ in Residues) | | | | |
| Time hours | $H_2SO_4$ (35% v, 70°C, 1:1) s/1 | HCl (75% v, 70°C, 1:1) s/1 | $H_2SO_4$ (35% v, 70°C, 1:1) s/1 | HCl (75% v, 70°C, 1:1) s/1 |
| 1 | 0.16 | 0.12 | 0.070 | 0.057 |
| 2 | 0.14 | 0.11 | 0.066 | 0.051 |
| 4 | 0.13 | 0.10 | 0.061 | 0.051 |
| 6 | 0.12 | 0.10 | 0.056 | 0.046 |

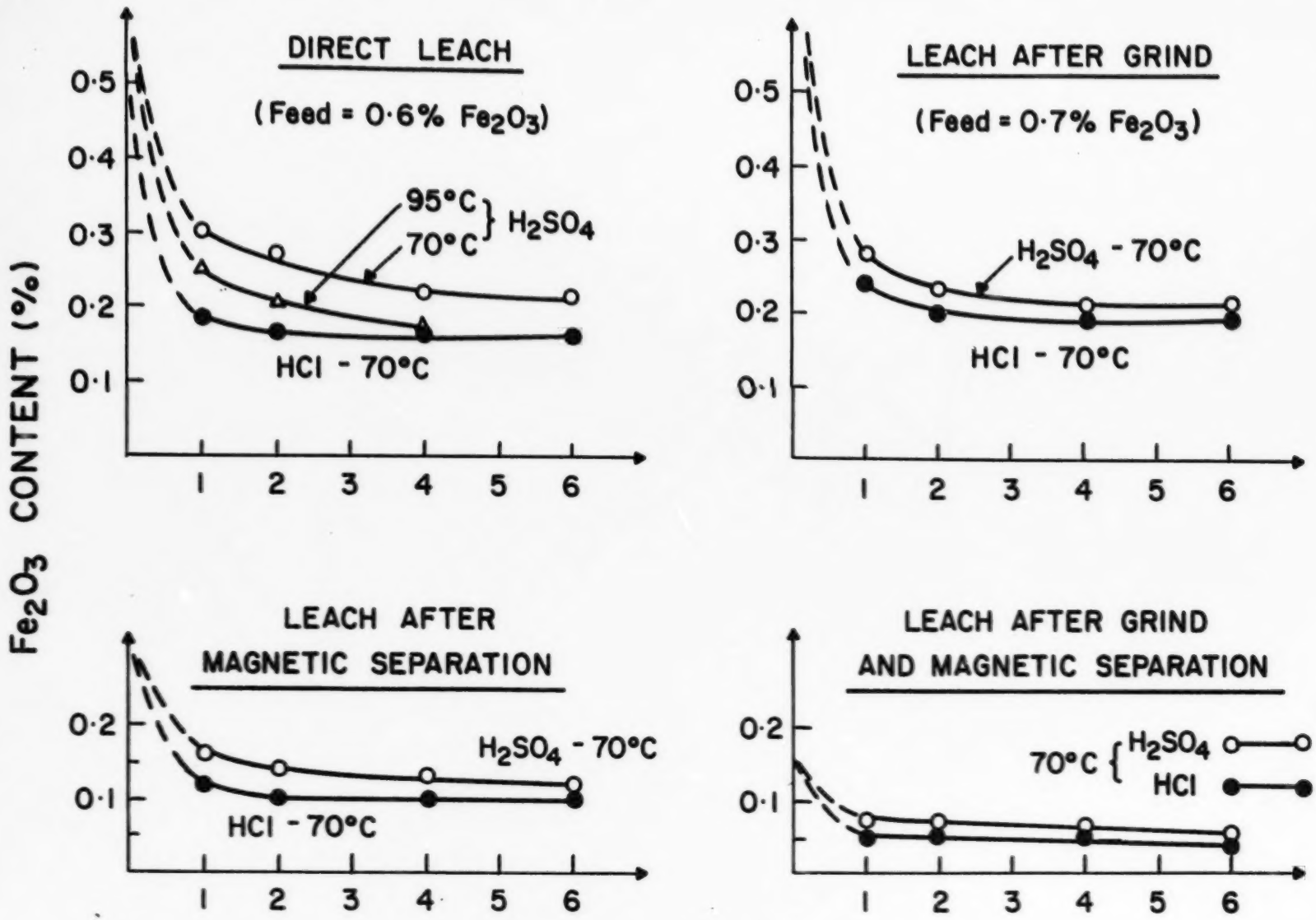


Fig. 7 - EFFECT OF T°, TIME AND PRE-TREATMENT ON IRON REMOVAL BY ACID LEACH

Despite the higher extraction obtained with the hydrochloric acid, leaching was pursued solely with sulphuric acid because of its lower cost and ready availability in the vicinity of the ore deposit. Four series of tests were made on representative samples from the concentrates produced by the various flotation approaches. These were aimed at:

1) maximizing the iron extraction from the unground feldspar by increasing the leach temperature to 95°C,
2) determining if ceramic-grade feldspar is obtainable without performing the acid leach after the fine grinding,
3) reducing the feldspar losses in the magnetic fractions by postponing this separation after the acid extraction and, finally
4) attaining the electrical porcelain grade (0.05% $Fe_2O_3$) by a short supplementary acid treatment at minus 45 µm size.

The conditions tested and the results obtained are reported in Table 12.

Table 12 - Acid leach followed by magnetic separation

| FELDSPAR CONCENTRATE | | 1st Acid Leach ($H_2SO_4$:35% v, 70-95°C, 5 h, 1:1 s/l) | | | 2nd Acid Leach (35% $H_2SO_4$, 70°C, 1 h) Feed: Sala Non-Mags | |
|---|---|---|---|---|---|---|
| Origin | Analysis % | -I- Residues 95°C(70°C) | -II- H-I Stearns** Non-mags | -III- Sala HGMS*** Non-mags | -IV- Acid Residues | |
| | | | | | -45 µm (1) | -45 µm (2) |
| Scrub & Float | $Fe_2O_3$:0.58<br>$TiO_2$:0.10<br>MgO:0.18 | 0.20<br>0.076<br>0.10 | 0.12<br>0.050<br>0.06 | 0.080<br>0.025<br>0.04 | 0.050<br>0.019<br>0.04 | 0.048<br>0.015<br>0.04 |
| Acid-alkali Treatment & Float | $Fe_2O_3$:0.61*<br>$TiO_2$:0.11*<br>MgO:0.25* | (0.19)<br>(0.074)<br>(0.06) | 0.12<br>0.045<br>0.04 | 0.078<br>0.028<br>0.04 | 0.054<br>0.020<br>0.04 | 0.048<br>0.013<br>0.04 |
| Sized Split Flotation | $Fe_2O_3$:0.55<br>$TiO_2$:0.11<br>MgO:0.26 | 0.19<br>0.08<br>0.07 | 0.115<br>0.037<br>0.05 | 0.079<br>0.026<br>0.04 | 0.052<br>0.022<br>0.04 | 0.046<br>0.011<br>0.04 |
| Feldspar lost (%) (average) | | - | 1.4 | 7.3 | - | - |

* Analyses before the acid-alkali treatment.
** Two passes at maximum strength (0.5 Tesla) and minimum air gap (1 mm).
***After grinding to -74 µm.
(1) Minus 45 µm fraction screened from -74 µm material.
(2) Plus 45 µm fraction reground to -45 µm.

The iron removal study established the following points:

- Albeit increasing the iron oxide dissolution rate, temperature raising from 70 to 95°C failed to lower the final $Fe_2O_3$ content when a 5-hour sulphuric acid leach was used.
- It is not necessary to grind prior to the acid leach to attain the ceramic feldspar iron requirement provided the leaching time is long enough (see Tables 12-III versus 11-III) and the magnetic separation is made at minus 74 µm using a high-gradient machine.
- The sequence of acid leaching followed by magnetic separation reduced the overall feldspar losses in the magnetic fractions of the Stearns and Sala separators from 4.6% to 1.4% and from 9.7 to 7.3%, respectively.
- A premium electrical porcelain grade (0.05% $Fe_2O_3$) was obtained by an additional 1-hour 70°C sulphuric acid leach at minus 45 µm.
- In addition to removing iron, the magnetic and acid treatments were also effective for reducing the magnesium and titanium impurities.

## ALTERNATIVE FLOWSHEETS FOR UPGRADING FELDSPAR

Using the best flotation, leaching and magnetic separation conditions found in the laboratory work, three integrated alternative flowsheets were designed and tested. A batch pilot plant procedure was used, in which ten 700 g lots of primary feldspathic sand were floated, and the concentrates combined for the acid and magnetic treatment. The main difference between the flowsheets was in the surface preparation stage prior to the feldspar flotation, namely: a) acid-alkali treatment, b) caustic attrition and desliming, and c) alkali scrubbing, desliming and sizing. The detailed processing conditions, products analyses and material balances of Flowsheets A, B and C are given in Appendices III, IV and V, respectively. These are also summarized in Table 13, while comparative flowcharts appear in Fig. 8.

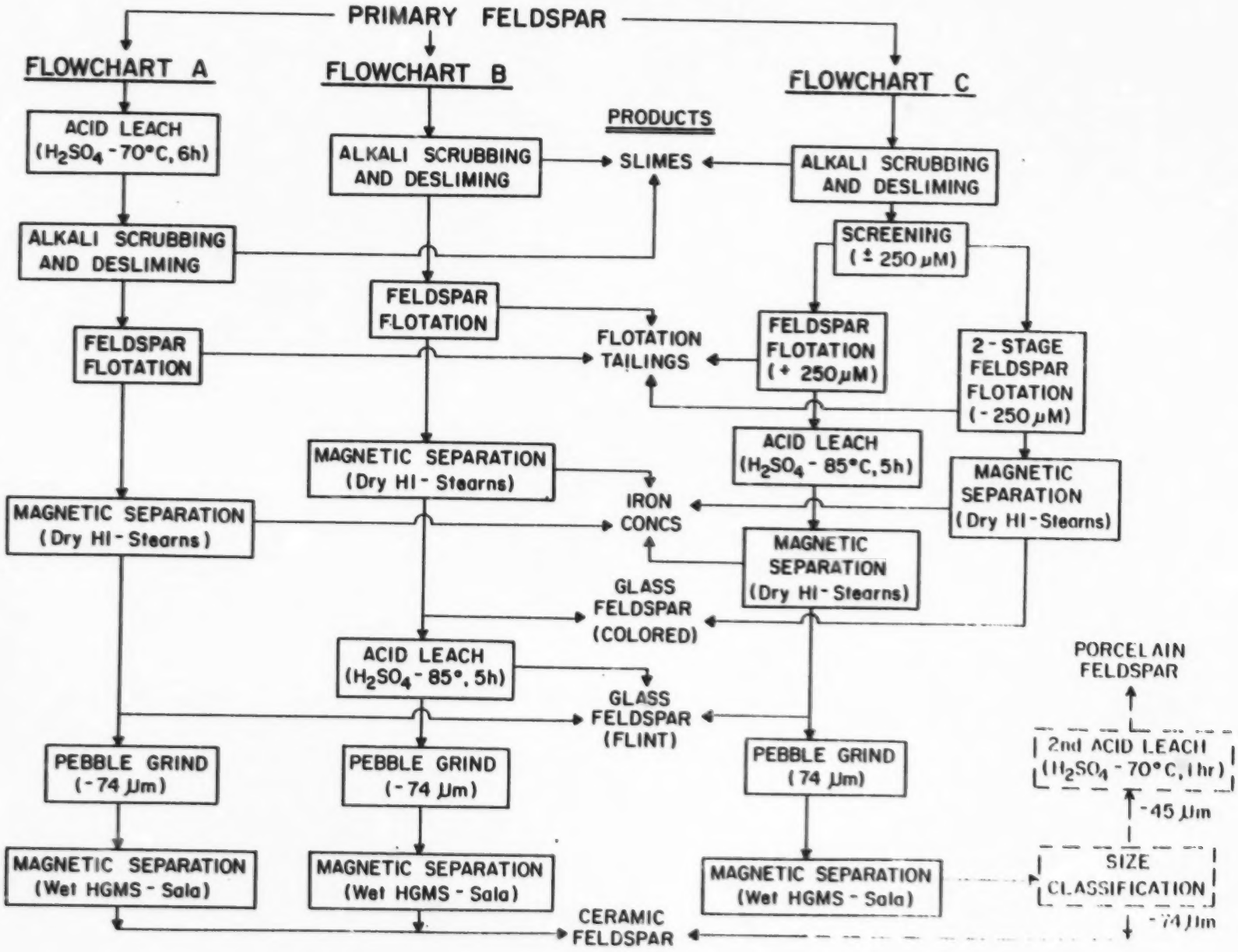


Fig. 8 - ALTERNATIVE FLOWSHEETS FOR UPGRADING FELDSPAR

Table 13 - Testing and results of integrated flowsheets

| Components Analysed (%) | Flowsheet A* | | Flowsheet B** | | | Flowsheet C*** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Flint-Glass Feldspar | Ceramic Feldspar | Glass Feldspar | | Ceramic Feldspar | Glass Feldspar | | Ceramic Feldspar | |
| | | | Coloured | Flint | | Coloured | Flint | Ceramic | Porcelain |
| $Al_2O_3$ | 18.3 | 18.4 | 17.9 | 18.0 | 18.2 | 18.0 | 18.3 | 18.3 | 18.2 |
| $K_2O$ | 11.2 | 11.3 | 11.1 | 11.3 | 11.4 | 10.8 | 11.4 | 11.3 | 11.3 |
| $Na_2O$ | 2.7 | 2.7 | 2.5 | 2.5 | 2.6 | 2.7 | 2.7 | 2.7 | 2.7 |
| CaO | 0.41 | 0.43 | 0.40 | 0.35 | 0.33 | 0.36 | 0.28 | 0.34 | 0.31 |
| $Fe_2O_3$ | 0.11 | 0.08 | 0.27 | 0.12 | 0.08 | 0.27 | 0.11 | 0.076 | 0.049 |
| $SiO_2$ | 67.3 | 67.1 | 67.5 | 67.1 | 66.8 | 67.5 | 66.9 | 66.8 | 66.9 |
| Feldspar Recovery | 90.2% | | 86.5% | | | 88.4% | | | |

* Acid-alkali treatment, desliming, flotation, H-I dry magnetic separation, grind and HGMS wet magnetic separation.

** Alkali attrition and desliming, flotation, H-I dry magnetic separation, $H_2SO_4$ acid leach, grind and HGMS wet magnetic separation.

***Alkali scrubbing, desliming and sizing, split flotation, $H_2SO_4$ acid leach, H-I dry magnetic separation, grinding, HGMS wet magnetic separation, sizing and releaching to porcelain grade.

In the batch pilot plant tests, porcelain feldspar was produced only with Flowsheet C. It has been demonstrated in the laboratory work however, that this grade is also attainable by the other two approaches. With each flowsheet equal quantities of the finished products were produced but, in plant practice, the production should match the market demand.

During the stage-grinding to minus 74 µm, it was observed that the dark minerals reported in greater concentration with the finest material. Iron and titanium oxide analyses of the Sala non-magnetic sized products confirmed the presence of higher impurities as the size goes down as shown in Table 14.

Table 14 - Size distribution of impurities in ceramic feldspar

| Sala Non-Magnetics (Product Origin) | +45 µm | | -45+25 µm | | -25 µm | |
|---|---|---|---|---|---|---|
| | % $Fe_2O_3$ | % $TiO_2$ | % $Fe_2O_3$ | % $TiO_2$ | % $Fe_2O_3$ | % $TiO_2$ |
| Scrub & Float | 0.06 | 0.01 | 0.07 | 0.04 | 0.11 | 0.09 |
| Split-Flotation | 0.05 | 0.01 | 0.08 | 0.03 | 0.10 | 0.08 |
| Acid-alkali & Float | 0.07 | 0.02 | 0.07 | 0.04 | 0.09 | 0.07 |

These results suggest that the porcelain-feldspar iron specification (0.05% $Fe_2O_3$) might be obtainable without the second acid leach, i.e. by carefully selecting classified material for regrinding to minus 45 µm. Further investigation and analyses would be necessary to achieve this aim.

## EVALUATION OF FELDSPAR PRODUCTS

The feldspar concentrates obtained in our laboratory were found to be chemically similar to the best potash feldspar worldwide, as shown in Table 15.

Table 15 - Comparative composition of high-grade potash feldspars (2,3)

| Component | King Mountain K-40 | Magdalen Glass-grade | Oy Lolya FFF-grade | Magdalen Ceramic | K/S Norfloat Potash | Magdalen Porcelain |
|---|---|---|---|---|---|---|
| $Al_2O_3$ | 18.3 | 18.3 | 18.5 | 18.3 | 18.7 | 18.2 |
| $K_2O$ | 10.1 | 11.4 | 8.1 | 11.3 | 11.1 | 11.3 |
| $Na_2O$ | 3.8 | 2.7 | 5.0 | 2.7 | 3.4 | 2.7 |
| CaO | 0.4 | 0.3 | 0.6 | 0.3 | 0.5 | 0.3 |
| $SiO_2$ | 67.1 | 66.9 | 67.5 | 66.3 | 65.4 | 66.9 |
| $Fe_2O_3$ | 0.07 | 0.11 | 0.10 | 0.08 | 0.06 | 0.05 |
| LOI | 0.3 | 0.3 | NA | 0.3 | 0.3 | 0.3 |

Portions of the Magdalen feldspars were thus submitted to various Canadian users for evaluation. Regarding the glass-grade feldspar, M.J. Hilson of Domglass Inc. wrote: "We have examined the feldspar sample sent and advise that the material has definite potential as a glass making raw material" (10).

The porcelain feldspar was examined by Lapp Insulator, Interplace Corporation. Further to standard tests including sieve and sub sieve size analyses (see graph in Fig. 9), a bloat test-count and a firing curve of an electrical porcelain body, R.F. Fitzsimmons made the following comments (11):

1) a finer sub sieve distribution would be required,
2) the bloat count should be reduced from 4-5 to 3-3,
3) the firing curve was satisfactory for electrical porcelain.

He then concluded that, with some grinding and processing adjustments, "The Canadian feldspar could probably be used in porcelain bodies".

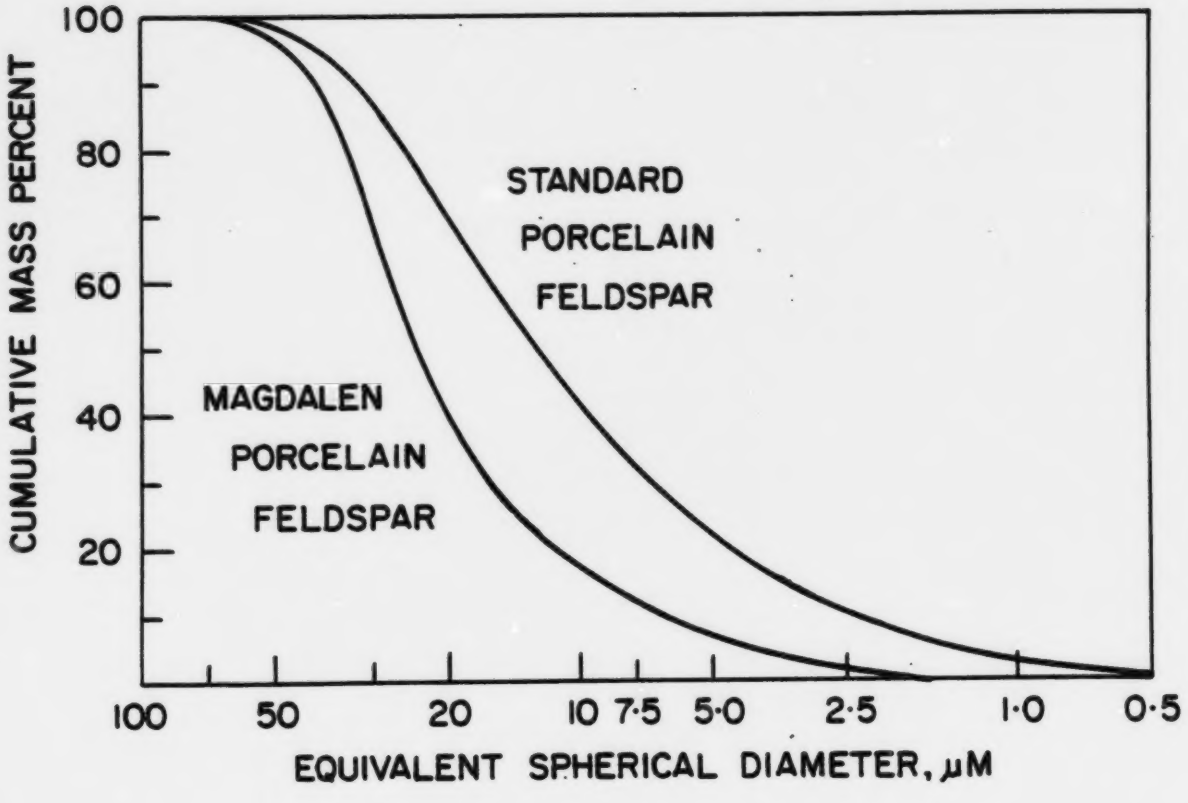


Fig. 9 - Size Comparison of "Magdalen" and "Standard" Electrical Porcelain Feldspars

## CONCLUSIONS

Up to now, commercial feldspars of high quality have been produced from pegmatite dykes. The purpose of this study was to demonstrate that feldspathic products of comparable quality could be derived from quartz - feldspar marine sand deposit. The procedure developed at CANMET involved (1) a primary feldspar separation by differential flotation, which was performed in a previous pilot plant study, (2) a surface preparation step using either alkali scrubbing or acid-alkali treatment both followed by feldspar cleaner flotation and, finally, (3) an acid leach and/or magnetic separation to remove the iron stains and minerals for the final upgrading of the feldspar.

In an attempt to optimize the feldspar grade and recovery, the unit operations were investigated separately under various conditions and, subsequently, integrated in the most promising alternative flowsheets. The layouts selected for testing aimed at different desirable objectives, namely, simplicity of treatment (Flowchart A) economy in operating and equipment costs (e.g. Flowchart B), and diversity and quality of the finished concentrates. Flowsheet A is the simplest approach and returned the best feldspar end products, but it requires 45% more leaching capacity than the other two alternatives and does not allow the production of the coloured glass quality. On the other hand, the dry H-I magnetic separation with Flowsheets B and C has the limitation that it is either totally or partially carried out before the acid leach with resulting additional feldspar losses (i.e., 2.1 and 1.3%, respectively). Flowsheet C has the additional inconvenience of requiring more equipment (e.g. screens and float cells) without improving appreciably the feldspar grade-recovery (see Fig. 5 and 6).

As a means to minimize costs while still producing four high quality feldspar products, the author is proposing a slightly modified version of Flowsheet B with improvements on the following grounds, namely:

1) magnetic separation prior to acid leach, only as needed, i.e. for production of coloured glass feldspar;
2) reduction in equipment by the alternate use of the leaching and dry magnetic separation facilities, as illustrated in Fig. 10.

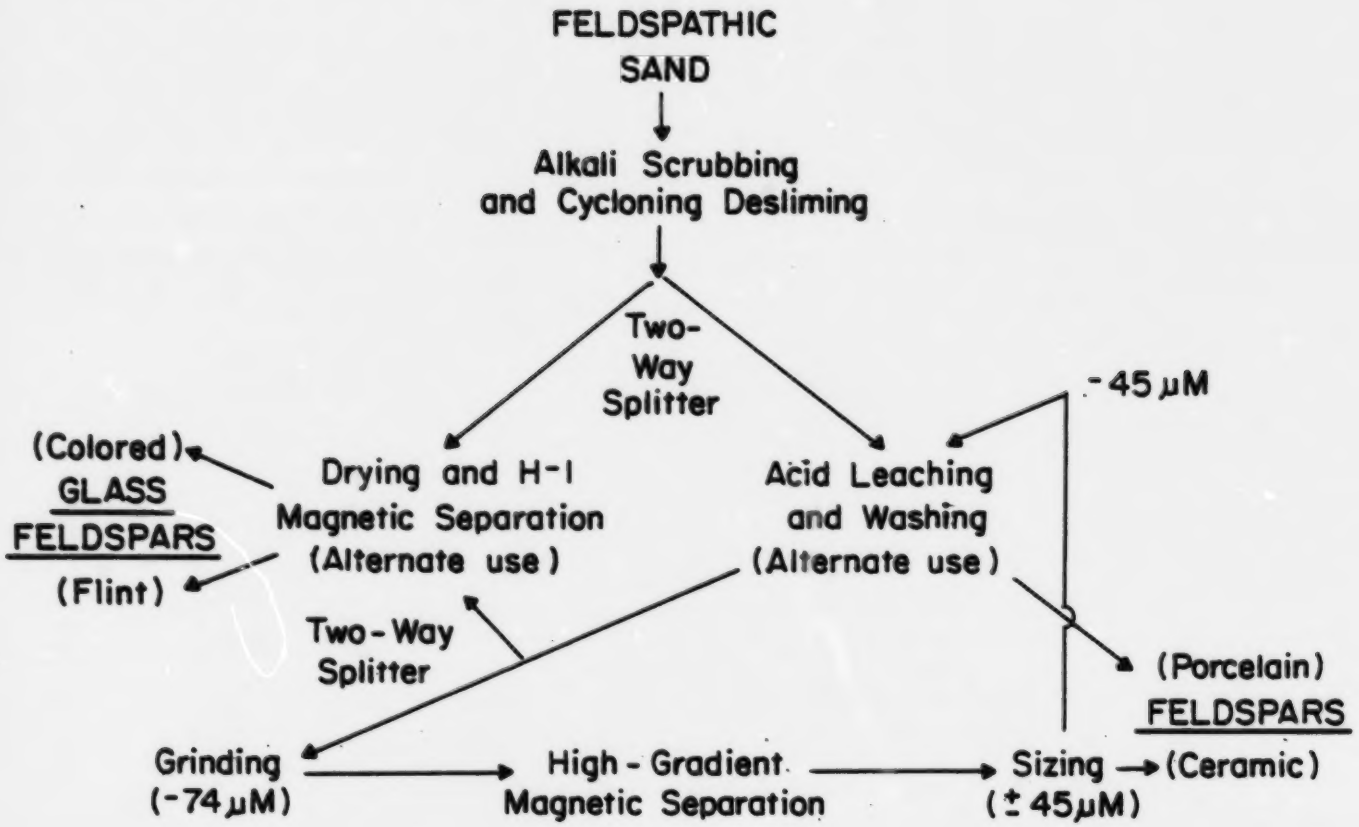


Fig. 10 - Proposed Flowsheet for Upgrading Feldspar at Minimal Operating and Capital Costs

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## APPENDIX I - FELDSPAR-QUARTZ SEPARATION FLOTATION

### Table A - Effects of Grinding to Minus 74 µm

Part 1 - Reagents and Conditions

| Operation | Time min | Density % solid | Reagents Kg/t | | pH |
|---|---|---|---|---|---|
| | | | $H_2SO_4$ | PDD | |
| Grinding | 4 x 40 | 60 | - | - | - |
| Conditioning | | | | | |
| Test GF-1 | 5 | 60 | 4.0 | 3.7 | 2.1-2.2 |
| Test GF-2 | 5 | 60 | 4.0 | 4.5 | 2.1-2.3 |
| Test GF-3 | 5 | 60 | 4.2 | 4.0 | 2.0-2.1 |
| Flotation | 4 | 25 | 1.0 | - | 2.3-2.6 |

Part 2 - Weight and Analysis of Products

| Test | Products | Wt % | Analysis, % | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Feldspar components | | | | Total Feldspar | Silica | | Oxide | | |
| | | | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | | $SiO_2$ | Quartz | $Fe_2O_3$ | MgO | $TiO_2$ |
| GF-1 | Feldspar conc | 73.4 | 18.1 | 10.7 | 2.5 | 0.55 | 87.1 | 66.0 | 9.4 | 0.68 | 0.25 | 0.10 |
| | Flot tailing | 26.6 | 7.5 | 3.6 | 1.4 | 0.36 | 44.9 | 85.8 | 63.1 | 0.55 | 0.22 | 0.11 |
| GF-2 | Feldspar conc | 76.9 | 17.6 | 10.5 | 2.5 | 0.56 | 85.9 | 66.8 | 10.9 | 0.67 | 0.21 | 0.09 |
| | Flot tailing | 23.1 | 3.7 | 1.7 | 0.9 | 0.21 | 19.3 | 92.2 | 80.0 | 0.47 | 0.18 | 0.12 |
| GF-3 | Feldspar conc | 75.0 | 17.9 | 10.6 | 2.5 | 0.47 | 86.1 | 66.5 | 10.8 | 0.71 | 0.24 | 0.09 |
| | Flot tailing | 25.0 | 4.4 | 2.4 | 1.1 | 0.28 | 24.9 | 90.7 | 74.5 | 0.35 | 0.13 | 0.10 |

Part 3 - Distribution %

| Test | Products | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | Feldspar | $SiO_2$ | Quartz | $Fe_2O_3$ | MgO | $TiO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GF-1 | Feldspar conc | 87.0 | 89.1 | 83.1 | 80.8 | 87.3 | 68.0 | 29.2 | 77.4 | 75.7 | 71.6 |
| | Flot tailing | 13.0 | 10.9 | 16.9 | 19.2 | 12.7 | 32.0 | 70.8 | 22.6 | 24.3 | 28.4 |
| GF-2 | Feldspar conc | 94.0 | 95.4 | 90.2 | 89.9 | 93.7 | 70.7 | 31.2 | 82.6 | 79.5 | 71.4 |
| | Flot tailing | 6.0 | 4.6 | 9.8 | 10.1 | 6.3 | 29.3 | 68.8 | 17.4 | 20.5 | 28.6 |
| GF-3 | Feldspar conc | 92.4 | 92.9 | 87.2 | 83.4 | 91.2 | 68.7 | 30.3 | 85.9 | 84.7 | 69.2 |
| | Flot tailing | 7.6 | 7.1 | 12.8 | 16.6 | 8.8 | 31.3 | 69.7 | 14.1 | 15.3 | 30.8 |

APPENDIX I (continued)

Table B - Effect of Alkali Scrubbing

Part 1 - Reagents and Conditions

| Operation | Time min | Density % solid | Reagents Kg/t | | | pH |
|---|---|---|---|---|---|---|
| | | | NaOH | $H_2SO_4$ | PDD | |
| Scrubbing (Desliming 2X) | 15 | 75 | 5 | - | - | 13.6 |
| Conditioning: | | | | | | |
| Test SF-1 | 5 | 60 | - | 2.6 | 1.1 | 2.1-2.2 |
| Test SF-2 | 5 | 60 | - | 2.8 | 1.3 | 2.0-2.1 |
| Test SF-3 | 5 | 60 | - | 2.8 | 1.2 | 1.8-1.9 |
| Flotation | 4 | 25 | - | 1.0 | - | 2.3-2.5 |

Part 2 - Weight and Analysis of Products

| Test | Products | Wt % | Analysis, % | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Feldspar components | | | | Total Feldspar | Silica | | Oxides | | |
| | | | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | | $SiO_2$ | Quartz | $Fe_2O_3$ | MgO | $TiO_2$ |
| SF 1,2,3 | Feed | 100.0 | 14.2 | 8.3 | 2.1 | 0.50 | 69.2 | 73.2 | 28.6 | 0.62 | 0.23 | 0.10 |
| | Slimes | 1.0 | 12.3 | 3.8 | 1.8 | 2.40 | 47.6 | 61.5 | 31.3 | 6.90 | 4.29 | 0.59 |
| | Deslimed feed | 99.0 | 14.3 | 8.4 | 2.1 | 0.48 | 69.7 | 73.4 | 28.6 | 0.56 | 0.19 | 0.09 |
| SF-1 | Feldspar conc | 71.4 | 18.1 | 10.8 | 2.6 | 0.53 | 88.4 | 66.3 | 9.9 | 0.59 | 0.20 | 0.09 |
| | Flot tailing | 27.6 | 4.9 | 2.1 | 1.1 | 0.24 | 22.9 | 90.3 | 75.7 | 0.44 | 0.17 | 0.08 |
| SF-2 | Feldspar conc | 75.5 | 17.3 | 10.5 | 2.5 | 0.61 | 86.3 | 67.5 | 12.1 | 0.58 | 0.16 | 0.08 |
| | Flot tailing* | 24.5 | 3.5 | 1.4 | 0.7 | 0.16 | 15.0 | 92.5 | 82.1 | 0.60 | 0.28 | 0.11 |
| SF-3 | Feldspar conc | 73.4 | 18.0 | 10.8 | 2.5 | 0.59 | 87.9 | 66.3 | 9.8 | 0.55 | 0.19 | 0.11 |
| | Flot tailing* | 25.6 | 4.5 | 1.5 | 1.0 | 0.27 | 18.7 | 91.2 | 79.7 | 0.50 | 0.22 | 0.10 |

*Averaged from two tests

Part 3 - Distribution %

| Test | Products | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | Feldspar | $SiO_2$ | Quartz | $Fe_2O_3$ | MgO | $TiO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SF-1,2,3 | Slimes | 0.9 | 0.5 | 0.9 | 4.8 | 0.7 | 0.8 | 1.1 | 11.2 | 18.5 | 6.0 |
| SF-1 | Feldspar concentrates | 89.7 | 92.5 | 85.2 | 81.0 | 90.3 | 65.0 | 25.0 | 68.9 | 61.4 | 70.0 |
| SF-2 | | 93.0 | 95.4 | 90.8 | 87.7 | 94.0 | 68.7 | 30.9 | 66.5 | 51.9 | 65.0 |
| SF-3 | | 91.2 | 94.9 | 87.0 | 82.1 | 92.4 | 67.0 | 25.8 | 67.4 | 58.4 | 71.4 |

APPENDIX I (continued)

Table C - Acid - Alkali Treatment prior to Flotation

Part 1 - Reagents and Conditions

| Operation | Time min | Density % solid | Reagents Kg/t | | | pH |
|---|---|---|---|---|---|---|
| | | | $H_2SO_4$ | NaOH | PDD | |
| Acid-leach | 360 | 50 | 100e | - | - | 0.1 |
| Alkali scrubbing & Desliming(2X) | 10 | 75 | - | 5.0 | - | 13.1 |
| Conditioning: | | | | | | |
| Test AAF-1 | 5 | 60 | 1.9 | - | 0.60 | 2.1-2.3 |
| Test AAF-2 | 5 | 60 | 2.1 | - | 0.70 | 2.0-2.2 |
| Test AAF-3 | 5 | 60 | 2.0 | - | 0.65 | 2.2-2.3 |
| Flotation | 4 | 24 | 0.9 | - | - | 2.3-2.6 |

e=estimated

Part 2 - Weight and Analysis of Products

| Test | Products | Wt % | Analysis, % | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Feldspar components | | | | Total Feldspar | Silica | | Oxides | | |
| | | | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | | $SiO_2$ | Quartz | $Fe_2O_3$ | MgO | $TiO_2$ |
| AAF 1,2,3 | Feed | 100.0 | 14.8 | 8.8 | 2.1 | 0.35 | 71.7 | 72.6 | 27.4 | 0.20 | 0.07 | 0.08 |
| | Slimes | 0.4 | 11.5 | 4.5 | 2.1 | 2.09 | 54.8 | 68.0 | 35.0 | 2.27 | 1.58 | 1.43 |
| Feed | (Leached & Deslimed) | 99.6 | 14.8 | 8.8 | 2.1 | 0.34 | 72.3 | 72.9 | 27.2 | 0.19 | 0.06 | 0.07 |
| AAF-1 | Feldspar conc | 73.7 | 18.4 | 11.2 | 2.6 | 0.34 | 89.9 | 66.3 | 9.4 | 0.21 | 0.05 | 0.06 |
| | Flot tailing | 25.9 | 5.1 | 2.3 | 0.9 | 0.29 | 22.6 | 90.6 | 76.7 | 0.13 | 0.08 | 0.09 |
| AAF-2 | Feldspar conc | 77.7 | 17.8 | 10.9 | 2.5 | 0.33 | 87.2 | 67.6 | 12.2 | 0.20 | 0.05 | 0.07 |
| | Flot tailing | 21.9 | 3.1 | 1.2 | 0.5 | 0.20 | 12.3 | 94.2 | 87.0 | 0.14 | 0.09 | 0.09 |
| AAF-3 | Feldspar conc | 76.3 | 18.2 | 11.0 | 2.6 | 0.40 | 89.0 | 66.6 | 10.3 | 0.20 | 0.05 | 0.06 |
| | Flot tailing | 23.3 | 4.2 | 1.7 | 0.7 | 0.31 | 17.5 | 92.3 | 81.8 | 0.16 | 0.10 | 0.09 |

Part 3 - Distribution %

| Test | Products | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | Feldspar | $SiO_2$ | Quartz | $Fe_2O$ | MgO | $TiO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AAF-1,2,3 | Slimes | 0.3 | 0.2 | 0.4 | 2.4 | 0.3 | 0.4 | 0.5 | 4.6 | 9.0 | 7.4 |
| AAF-1 | Feldspar concentrates | 90.9 | 93.1 | 88.8 | 75.1 | 90.6 | 67.0 | 25.7 | 77.0 | 58.3 | 60.5 |
| AAF-2 | | 95.0 | 96.8 | 94.3 | 83.4 | 95.8 | 71.5 | 33.1 | 79.7 | 60.3 | 70.0 |
| AAF-3 | | 93.1 | 95.3 | 92.0 | 78.9 | 94.1 | 70.0 | 70.4 | 76.7 | 56.5 | 63.6 |

# APPENDIX II - SIZED SPLIT FLOTATION

## Part 1 - Reagents and Conditions

| Operation | | Time min | Density % solid | Reagents | | | pH |
|---|---|---|---|---|---|---|---|
| | | | | NaOH | $H_2SO_4$ | PDD | |
| Scrubbing (Desliming 2X) Screening (±250 µm) | | 15 | 75 | 5 | - | - | 13.5 |
| Conditioning | Test C & F-1 | 5 | 57 | - | 0.85&1.05 | 0.45&0.70 | 2.0-2.3 |
| (C=+250 µm) | Test C & F-2 | 5 | 57 | - | 0.95&1.15 | 0.55&0.80 | 2.0-2.2 |
| (F=-250 µm) | Test C & F-3 | 5 | 57 | - | 0.90&1.10 | 0.50&0.75 | 2.1-2.2 |
| Flotation: | Tests C-1,2,3 | 4 | 25 | - | 0.5 | - | 2.4-2.7 |
| | Tests F-1,2,3 | 4 | 23 | - | 0.5 | - | 2.3-2.6 |
| | (2nd stage) | 4 | 17 | - | 0.3 | 0.25 | 2.2-2.5 |

## Part 2 - Results (Overall Basis)

| Test | Products | Wt % | Analysis, % | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Feldspar components | | | | Total Feldspar | Silica | | Oxides | | |
| | | | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | | $SiO_2$ | Quartz | $Fe_2O_3$ | MgO | $TiO_2$ |
| C+F 1,2,3 | Feed | 100.0 | 14.2 | 8.4 | 2.0 | 0.46 | 68.9 | 72.6 | 29.3 | 0.60 | 0.31 | 0.12 |
| | Slimes | 0.9 | 12.5 | 3.6 | 2.2 | 1.71 | 48.4 | 59.6 | 31.6 | 6.30 | 5.23 | 0.80 |
| | Deslimed feed | 99.1 | 14.2 | 8.4 | 2.1 | 0.45 | 68.5 | 72.1 | 29.3 | 0.55 | 0.27 | 0.11 |
| C&F 1 | Feldspar conc | 72.4 | 18.3 | 11.1 | 2.5 | 0.43 | 89.0 | 66.1 | 9.4 | 0.57 | 0.26 | 0.11 |
| | Flot tail | 26.7 | 3.9 | 1.6 | 0.8 | 0.12 | 16.5 | 92.0 | 81.4 | 0.52 | 0.32 | 0.11 |
| C&F 2 | Feldspar conc | 73.8 | 17.8 | 10.8 | 2.4 | 0.64 | 87.4 | 66.9 | 11.0 | 0.54 | 0.28 | 0.12 |
| | Flot tail | 25.3 | 3.4 | 1.3 | 0.7 | 0.15 | 14.2 | 92.8 | 84.2 | 0.55 | 0.29 | 0.10 |
| C&F 3 | Feldspar conc | 72.9 | 18.1 | 10.9 | 2.4 | 0.60 | 88.2 | 66.5 | 10.3 | 0.55 | 0.24 | 0.10 |
| | Flot tail | 26.2 | 3.7 | 1.5 | 0.7 | 0.20 | 16.0 | 92.3 | 82.3 | 0.61 | 0.29 | 0.12 |

## Distribution %

| Test | Products | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | Feldspar | $SiO_2$ | Quartz | $Fe_2O_3$ | MgO | $TiO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C&F 1,2,3 | Slimes | 0.7 | 0.3 | 0.9 | 3.0 | 0.6 | 0.7 | 0.8 | 8.5 | 13.7 | 5.7 |
| C&F -1 | Feldspar concentrates | 92.1 | 94.7 | 88.6 | 86.6 | 93.0 | 65.6 | 23.8 | 68.5 | 59.4 | 68.9 |
| C&F -2 | | 93.2 | 95.7 | 90.1 | 89.8 | 94.2 | 67.3 | 27.9 | 67.8 | 63.7 | 73.4 |
| C&F -3 | | 92.2 | 95.0 | 89.4 | 86.6 | 93.3 | 66.3 | 25.6 | 65.4 | 60.2 | 65.9 |

APPENDIX II (continued)

Part 3 - Results (Size Basis)

| Test | Products | Wt % | Analysis, % | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Feldspar components | | | | Total Feldspar | Silica | | Oxides | | |
| | | | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | | $SiO_2$ | Quartz | $Fe_2O_3$ | MgO | $TiO_2$ |
| C-1,2,3 | Slimes | 0.8 | 14.2 | 4.2 | 2.6 | 1.94 | 56.4 | 56.0 | 22.6 | 6.93 | 6.15 | 0.93 |
| C-1 | Feldspar conc | 79.9 | 18.7 | 11.5 | 2.5 | 0.48 | 91.5 | 65.6 | 7.3 | 0.38 | 0.15 | 0.06 |
| | Flot tailing | 19.3 | 6.4 | 2.6 | 1.1 | 0.19 | 25.6 | 87.5 | 72.2 | 0.75 | 0.43 | 0.14 |
| C-2 | Feldspar conc | 81.6 | 18.2 | 11.3 | 2.4 | 0.70 | 90.6 | 66.2 | 8.1 | 0.40 | 0.21 | 0.07 |
| | Flot tailing | 17.9 | 5.9 | 2.5 | 1.1 | 0.27 | 25.4 | 88.0 | 72.5 | 0.81 | 0.29 | 0.12 |
| C-3 | Feldspar conc | 80.5 | 18.6 | 11.4 | 2.4 | 0.66 | 91.0 | 65.8 | 7.8 | 0.41 | 0.18 | 0.06 |
| | Flot tailing | 18.7 | 6.0 | 2.6 | 1.1 | 0.35 | 26.4 | 87.6 | 71.2 | 0.98 | 0.35 | 0.13 |
| C-1,2,3 | Feed (c) | 100.0 | 16.1 | 9.7 | 2.2 | 0.56 | 78.5 | 69.8 | 19.8 | 0.52 | 0.25 | 0.08 |
| | | | | | | | | | | | | |
| F-1,2,3 | Slimes | 1.0 | 11.1 | 3.1 | 1.9 | 1.53 | 42.0 | 62.4 | 38.0 | 5.80 | 4.50 | 0.71 |
| F-1 | Feldspar conc | 63.6 | 17.6 | 10.4 | 2.6 | 0.35 | 85.3 | 66.9 | 12.6 | 0.84 | 0.43 | 0.19 |
| | Flot tailing | 35.4 | 2.3 | 0.9 | 0.6 | 0.07 | 10.7 | 94.8 | 87.3 | 0.37 | 0.25 | 0.09 |
| F-2 | Feldspar conc | 65.0 | 17.1 | 10.1 | 2.4 | 0.56 | 82.8 | 67.9 | 15.2 | 0.75 | 0.39 | 0.20 |
| | Flot tailing | 34.0 | 1.8 | 0.6 | 0.4 | 0.07 | 7.3 | 95.8 | 91.4 | 0.39 | 0.29 | 0.08 |
| F-3 | Feldspar conc | 64.0 | 17.4 | 10.2 | 2.5 | 0.50 | 84.0 | 67.4 | 14.1 | 0.75 | 0.34 | 0.17 |
| | Flot tailing | 35.0 | 2.2 | 0.8 | 0.5 | 0.11 | 9.4 | 95.2 | 89.3 | 0.37 | 0.25 | 0.11 |
| F-1,2,3 | Feed (c) | 100.0 | 12.0 | 6.9 | 1.8 | 0.35 | 57.6 | 77.0 | 40.4 | 0.70 | 0.38 | 0.16 |

Distribution %

| Test | Products | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | Feldspar | $SiO_2$ | Quartz | $Fe_2O_3$ | MgO | $TiO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C-1,2,3 | Slimes | 0.7 | 0.4 | 1.0 | 2.8 | 0.6 | 0.7 | 0.9 | 12.3 | 18.8 | 9.9 |
| C-1 | Feldspar concentrates | 91.7 | 94.5 | 89.5 | 88.7 | 93.1 | 75.1 | 29.2 | 60.7 | 48.0 | 58.2 |
| C-2 | | 92.7 | 95.0 | 90.0 | 89.2 | 93.6 | 76.9 | 33.4 | 62.0 | 62.2 | 66.1 |
| C-3 | | 92.4 | 94.6 | 89.5 | 86.6 | 93.2 | 75.9 | 31.8 | 57.6 | 55.9 | 60.6 |
| | | | | | | | | | | | |
| F-1,2,3 | Slimes | 0.9 | 0.5 | 1.1 | 4.4 | 0.7 | 0.8 | 0.9 | 8.4 | 11.7 | 4.5 |
| F-1 | Feldspar concentrates | 92.4 | 94.9 | 87.7 | 86.0 | 92.8 | 55.5 | 20.4 | 73.6 | 66.7 | 75.5 |
| F-2 | | 93.9 | 96.5 | 91.0 | 89.7 | 94.9 | 57.1 | 23.9 | 72.0 | 63.6 | 79.0 |
| F-3 | | 92.7 | 95.4 | 89.1 | 85.3 | 93.6 | 56.0 | 22.2 | 72.1 | 63.0 | 70.5 |

## APPENDIX III - FLOWSHEET A
(Data and Results)

### Part 1 - Reagents and Conditions

| Operation | Time min | Density % solid | Reagents Kg/t | | | pH |
|---|---|---|---|---|---|---|
| | | | NaOH | $H_2SO_4$ | PDD | |
| Acid-leach* | 360 | 50 | - | 100e | - | 0.1 |
| Scrubbing (Desliming 2X) | 15 | 75 | 5 | - | - | 13.1 |
| Conditioning | 5 | 60 | - | 2.0 | 0.65 | 2.1-2.3 |
| Flotation | 4½ | 25 | - | 0.9 | - | 2.3-2.6 |
| Magnetic separation** | | | | | | |

* Acid leach: 35% $H_2SO_4$, 70°C, and 1:1 solid/liquid by weight.
**Dry HI-Stearns separations: 0.5 Tesla, minimum gap; and
Wet Sala HGMS: 1.3 Tesla, 24 mm/s.

### Part 2 - Weight and Analysis of Products

| Products | Wt % | Feldspar components | | | | Total Feldspar | Silica | | Oxides | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | | $SiO_2$ | Quartz | $Fe_2O_3$ | MgO | $TiO_2$ |
| Ceramic feldspar | 35.5 | 18.4 | 11.3 | 2.7 | 0.43 | 91.8 | 67.1 | 7.6 | 0.079 | 0.04 | 0.026 |
| Glass feldspar | 35.5 | 18.3 | 11.2 | 2.7 | 0.41 | 91.1 | 67.3 | 8.2 | 0.11 | 0.04 | 0.045 |
| Flot tailing | 25.3 | 4.1 | 1.7 | 0.7 | 0.15 | 16.7 | 92.6 | 82.6 | 0.14 | 0.09 | 0.09 |
| Fe conc | 3.3 | 17.8 | 9.5 | 2.4 | 0.66 | 79.4 | 62.6 | 14.7 | 3.20 | 1.35 | 1.00 |
| Slimes | 0.4 | 11.5 | 4.5 | 2.1 | 2.10 | 54.8 | 68.0 | 35.0 | 2.27 | 1.58 | 1.43 |
| Feed (calcd) | 100.0 | 14.6 | 8.7 | 2.2 | 0.37 | 71.9 | 73.5 | 27.2 | 0.15 | 0.10 | 0.09 |

### Part 3 - Distribution %

| Products | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | Feldspar | $SiO_2$ | Quartz | $Fe_2O$ | MgO | $TiO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Feldspar conc | 88.6 | 91.3 | 87.8 | 81.4 | 90.2 | 64.9 | 20.6 | 44.4 | 27.8 | 29.1 |
| Flot tailing | 7.1 | 4.9 | 8.1 | 10.3 | 5.9 | 31.8 | 76.9 | 23.4 | 22.3 | 26.3 |
| Fe conc | 4.0 | 3.6 | 3.6 | 6.0 | 3.6 | 2.9 | 2.0 | 26.2 | 43.7 | 38.0 |
| Slimes | 0.3 | 0.2 | 0.4 | 2.3 | 0.3 | 0.4 | 0.5 | 6.0 | 6.2 | 6.6 |

## APPENDIX IV - FLOWSHEET B
(Data and Results)

### Part 1 - Reagents and Conditions

| Operation | Time min | Density % solid | Reagents Kg/t | | | pH |
|---|---|---|---|---|---|---|
| | | | NaOH | $H_2SO_4$ | PDD | |
| Scrubbing (Desliming 2X) | 15 | 75 | 5 | - | - | 13.6 |
| Conditioning | 5 | 60 | - | 2.8 | 1.2 | 2.0-2.2 |
| Flotation | 4 | 25 | - | 1.0 | 1.2 | 2.3-2.5 |
| Iron Removal* | | | | | | |

*Acid leach: 35% $H_2SO_4$, 70°C, 6 h and 1:1 solid/liquid by weight;
Dry HI-Stearns separations: 0.5 Tesla, minimum gap; and
Wet Sala HGMS: 1.3 Tesla, 24 mm/s.

### Part 2 - Weight and Analysis of Products

| Products | | Wt % | Feldspar components | | | | Total Feldspar | Silica | | Oxides | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | | $SiO_2$ | Quartz | $Fe_2O_3$ | MgO | $TiO_2$ |
| Ceramic feldspar | | 22.7 | 18.2 | 11.4 | 2.6 | 0.33 | 91.0 | 66.8 | 8.4 | 0.08 | 0.04 | 0.02 |
| Glass feldspar | Flint | 22.7 | 18.0 | 11.3 | 2.5 | 0.35 | 89.7 | 67.1 | 9.7 | 0.12 | 0.04 | 0.03 |
| | Coloured | 22.7 | 17.9 | 11.1 | 2.5 | 0.40 | 88.5 | 67.5 | 10.9 | 0.27 | 0.10 | 0.05 |
| Flot tailing | | 24.9 | 4.5 | 1.8 | 1.0 | 0.22 | 19.6 | 91.4 | 79.0 | 0.47 | 0.20 | 0.10 |
| Fe conc | | 6.0 | 16.0 | 8.3 | 2.3 | 2.00 | 66.9 | 62.8 | 24.8 | 3.60 | 1.80 | 2.03 |
| Slimes | | 1.0 | 12.3 | 3.8 | 1.7 | 2.40 | 37.5 | 58.4 | 41.3 | 6.90 | 5.20 | 1.25 |
| Feed (calcd) | | 100.0 | 14.5 | 8.6 | 2.1 | 0.44 | 70.8 | 72.7 | 27.1 | 0.51 | 0.25 | 0.18 |

### Part 3 - Distribution %

| Products | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | Feldspar | $SiO_2$ | Quartz | $Fe_2O$ | MgO | $TiO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Feldspar conc | 84.8 | 88.6 | 81.5 | 55.5 | 86.5 | 62.9 | 24.3 | 20.9 | 16.3 | 12.4 |
| Flot tailing | 7.7 | 5.2 | 11.3 | 11.9 | 7.1 | 31.3 | 72.1 | 42.5 | 19.9 | 13.7 |
| Fe conc | 6.7 | 5.8 | 6.4 | 27.2 | 5.7 | 5.0 | 2.5 | 23.0 | 43.1 | 67.0 |
| Slimes | 0.8 | 0.4 | 0.8 | 5.4 | 0.7 | 0.8 | 1.1 | 13.6 | 20.7 | 6.9 |

## APPENDIX V - FLOWSHEET C
(Data and Results)

### Part 1 - Reagents and Conditions

| Operation | Time min | Density % solid | Reagents Kg/t | | | pH |
|---|---|---|---|---|---|---|
| | | | NaOH | $H_2SO_4$ | PDD | |
| Scrubbing (Desliming 2X) Screening (±250 µm) | 15 | 75 | 5 | - | - | 13.4 |
| Conditioning: +250 µm | 5 | 60 | - | 0.9 | 0.50 | 2.1-2.3 |
| -250 µm | 5 | 55 | - | 1.1 | 0.75 | 2.0-2.2 |
| Flotation: +250 µm rougher | 4 | 25 | - | 0.4 | - | 2.4-2.6 |
| -250 µm rougher | 5 | 22 | - | 0.5 | - | 2.2-2.5 |
| -250 µm cleaner | 4 | 16 | - | 0.3 | 0.2 | 2.3-2.5 |
| Iron Removal* | | | | | | |

*1st Acid leach: 35% $H_2SO_4$, 85°C, 5 h and 1:1 solid/liquid by weight.
Dry HI-Stearns separations: 0.5 Tesla, minimum gap;
Wet Sala HGMS: 1.3 Tesla, 24 mm/s; and
2nd Acid leach: 35% $H_2SO_4$, 70°C, 1 h and 1:1 solid/liquid.

### Part 2 - Weight and Analysis of Products

| Products | | Wt % | Feldspar components | | | | Total Feldspar | Silica | | Oxides | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | | $SiO_2$ | Quartz | $Fe_2O_3$ | MgO | $TiO_2$ |
| Porcelain feldspar | | 17.2 | 18.2 | 11.3 | 2.68 | 0.31 | 91.0 | 66.9 | 8.4 | 0.049 | 0.04 | 0.02 |
| Ceramic feldspar | | 17.2 | 18.3 | 11.3 | 2.65 | 0.34 | 90.8 | 66.8 | 8.6 | 0.076 | 0.04 | 0.02 |
| Glass feldspar | Flint | 17.2 | 18.3 | 11.4 | 2.70 | 0.28 | 91.1 | 66.9 | 8.3 | 0.11 | 0.04 | 0.05 |
| | Coloured | 17.2 | 18.0 | 10.8 | 2.72 | 0.36 | 88.6 | 67.5 | 10.8 | 0.27 | 0.04 | 0.10 |
| Flot tailing | | 26.0 | 4.3 | 1.7 | 0.76 | 0.12 | 17.1 | 91.4 | 81.2 | 0.55 | 0.56 | 0.11 |
| Fe conc | | 4.4 | 16.7 | 7.6 | 2.88 | 2.07 | 78.6 | 63.5 | 11.5 | 3.78 | 2.16 | 1.29 |
| Slimes | | 0.8 | 12.8 | 3.5 | 1.70 | 0.35 | 36.8 | 63.4 | 44.9 | 6.15 | 3.36 | 0.78 |
| Feed (calcd) | | 100.0 | 14.5 | 8.5 | 2.20 | 0.34 | 70.4 | 72.0 | 28.2 | 0.44 | 0.29 | 0.12 |

### Part 3 - Distribution %

| Products | $Al_2O_3$ | $K_2O$ | $Na_2O$ | CaO | Feldspar | $SiO_2$ | Quartz | $Fe_2O$ | MgO | $TiO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Feldspar concs | 86.5 | 90.6 | 84.8 | 64.0 | 88.4 | 64.0 | 22.0 | 19.4 | 9.4 | 26.3 |
| Flot tailing | 7.7 | 5.2 | 8.7 | 8.7 | 6.3 | 31.4 | 74.9 | 32.2 | 49.3 | 23.0 |
| Fe conc | 5.1 | 3.9 | 5.8 | 26.5 | 4.9 | 3.9 | 1.8 | 37.3 | 32.2 | 45.7 |
| Slimes | 0.7 | 0.3 | 0.6 | 0.8 | 0.4 | 0.7 | 1.3 | 11.1 | 9.1 | 5.0 |